Ministry of Education and Scientific Research
Elmergib University
Faculty of Engineering Al-khoms
Department of Electrical and Computer Engineering
Elmergib Journal of Electrical and Electronic Engineering

وزارة التعليم العالي والبحث العلمي
جامعة المرقب
كلية الهندسة الخمس
قسم الهندسة الكهربائية والحاسوب
مجلة المرقب للهندسة الكهربائية والالكترونية

EJEEE
Volume **1,** Issue **1,** Nov **2022**

Sand Particle-Size Distribution in Air and their Effect on Microwave Propagation.

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Abstract- Microwave communication in southern parts of Libya may be affected by dust and sand storms. Microwave signals in AL-Joufrah region may suffer some attenuation and depolarization due to the presence of any carried particles in air. The study of electromagnetic signals propagation in microwave band through dust storm, requires knowledge of some of the electrical properties of the dust particles and climate conditions at the studied region. This required to collecting of samples of sand and dust particles, measure their concentration, particle size distribution and chemical analysis which essential to calculate the complex permittivity of samples. The main objective of this paper is to study the effect of sand and dust storms on microwave links, in this area by calculation the dielectric constant and depolarization factor of the dusty medium to estimate propagation constant and phase shift, which are needed to estimate signal attenuation and cross depolarization. In this work all the samples were collected from surface of ground to a height 9m, on the columns of the communication towers, at seven sites along the microwave link in the study region. From the calculations it was observed: The attenuation with visibility equal 8m (worst case) is serious, and approximately equal to 0.08665dB/km. Cross polarization can be serious when visibility fall below 10m over about 1km of path, and for visibility less than 50m phase shift increases rapidly with decreasing visibility..

Keywords - Attenuation, Cross polarization, Phase shift.

I. INTRODUCTION

Many radio communication applications require RF or microwave propagation from point to point very near the earth's surface examples of such applications include cellular telephones, pagers, broadcast television, radio stations, and differential GPS transmitters. The performance of service depends on many factors such as area of coverage, and climate conditions.

Propagation of microwave signal may suffer attenuation and cross polarization by the suspended particles such as dust, rain, snow, etc. The propagation of microwave signals in dust/sand storms found considerable interest recently, due the increasing number of terrestrial and satellite links established in the regions that frequently encounter dust or sand storms as well as many radar applications at high frequencies. The attenuation of the microwave signals in dusty media may arise from two physical mechanisms, (i) absorption and (ii) scattering of energy by the suspended dust particles. The centimeter waves bands are in the short wavelengths range; unfortunately, the shorter the wavelength the more attenuation will be induced by absorption and scattering due to rain drops, dust and sand particles in the radio path.

In desert, the effects of dust particles on microwave propagation have received some interest, and the knowledge of the complex permittivity of particles suspending or precipitating in the atmosphere is of importance in radio communication and radio meteorology. The attenuation, phase shift constants and cross polarization for a medium with dust or sand particles depends on the frequency, visibility, maximum particles-size, complex permittivity, shape of the scattering particles, concentration, and their orientation relative to the wave polarization, also the attenuation of electromagnetic waves due to dust is predominantly a function of the moisture content of the particles. The study of the effect on wireless communication networks due to dust and sand storms has been carried out by many researchers in countries like Libya [1, 2,

Submitted 29 July 2022; Final Version Received 19 Oct. 2022; Accepted 09 Sep. 2022; Published Online in Dec. 2022
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3, 4], Sudan [5, 15], Saudia Arabia [6] and Iraq [7]. The main object of this paper is to study the effect of dust and sand storms on wireless communication such as microwave links in the mid-north region of Libya (AL-Joufrah). The effect of the dust and sand on the microwave links in this area has not been studied, neither the effect of the humidity on the complex permittivity where by its effect on both attenuation and cross-polarization constants in this region, and also the effect of the height (height of towers) on the visibility where by its effect on both the attenuation and the cross-polarization constants in this region and due to the importance of this region for the Libyan microwave communication N.W., where it links north Libya by its south and east by west. Beside the expectation of different chemical analysis of the dust and sand, we have chosen this region for study.

II. DUST CONCENTRATION AND VISIBILITY

The number of particles suspended per unit volume of air (mass concentration), is one of the important parameters needed to compute the medium propagation constants.

A measure of severity of a dust storm that is used in meteorology is visibility; needless to mention that visibility decreases with increasing intensity of dust in a storm. It is found that visibility is related to the mass of dust per cubic meter of air by. [15]

$$M = {}^{C}\!/_{V^{\gamma}} \tag{1}$$

Where: M is the dust or sand mass in Kg/cubic meter of air, V is the visibility in Km, C and γ are constants that depend on the type of land from which the storm originated as well as the climatic conditions. The following values are applicable to conditions in Libya C = 2.3*10-5and γ= 1.07. [15]

As is well known visibility decreases with increasing number of particles in the atmosphere. As we saw previously by Eq. (1), the mass of suspending dust per unit volume of air is related to visibility. From measurements of dust concentration and visibility the following empirical relationship between visibility V (in km) and mass density ρ (in gm/cm3) has been obtained. [20]

$$\rho = {}^{C}\!/_{v \times V^{\gamma}} \tag{2}$$

Where: v is the relative volume occupied by particles (m^3 of particles /m^3 of air).The visibility during dust and/or sand storms increases as the height is increased. Chepil and Woodruff [21], arrived at the following empirical relation for the variation of dust or/and sand mass concentration (M, kg/m^3) with height (h, m).

$$M = {}^{a}\!/_{h^{b}} \tag{3}$$

Where: a and b are constants that vary a little from one year to another. They depend on the climatic conditions, meteorological factors and the particle size distribution of the dust and the sand. [5]

By substituting for M from Eq. (2) into Eq. (3), then visibility can be written as:

$$V^{\gamma} = {}^{C \times h^{b}}\!/_{a} \tag{4}$$

Let the visibility at some reference height h_o to be Vo, thus Eq. (4) yields:

$$V^{\gamma} = V_0^{\gamma}[\ h/h_0\ ]^{b} \tag{5}$$

Submitted 29 July 2022; Final Version Received 19 Oct. 2022; Accepted 09 Sep. 2022; Published Online in Dec. 2022

III. METHODOLOGY OF PARTICLES

To study the effect of sand and dust storms on microwave links we must review some important properties of particles, shape of the scattering particles, particles-size distribution, and their orientation relative to the wave polarization.

Dust and sand particles are random in shape and can't be classified as spheres, ellipsoid or otherwise. However, since computation of the effects of dust storms on wave propagation can be not easily carried out for the case of random shaped particles one needs to assume some suitable geometry. The nearest geometry that approximate particles are ellipsoid or sphere. This geometry has three degrees of freedom, and it gives good approximation to the shape of realistic dust particles, [19] as shown in Figure.1.

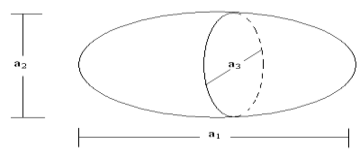

Figure 1 *Dust Particle Geometry Approximation.[19]*

The average ratio of the axes is given by 1: r_2: r_3 = 1:0.71:0.53; where $r_2 = a_2 / a_1$, $r_3 = a_3/a_2$. [5], [15], In stationary air condition, particles, which assumed ellipsoid shape, fell with the shortest axis vertical and the two other axis are randomly oriented in the horizontal plane, However, it is well known that turbulent air flow is present during dust and sand storms, this situation results in random orientation of the dust particles, Figure .2 shows the dusty medium model used in this study.

In this model the electromagnetic wave is propagated in the positive z direction, there are two important factors to estimate cross polarization discrimination change due to the effect of elliptical particles on microwave links. [14]

1- Orientation of the particle relative to the propagation field, determination of the orientation of particles during storms is difficult because this depends on the motion of air surrounding the particle.

2- The axes ratio a_1: a_2: a_3, the probability distributions of the a_2/a_1 and a_3/a_2 ratios are of interest and use in estimate attenuation and phase constants for ellipsoid particles.

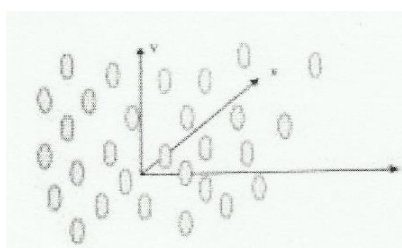

***Figure 2**. Dusty Medium Model*

IV. MEDIUM PERMITTIVITY AND DEPOLARIZATION FACTOR

on microwave propagation it will be assumed that the medium (air with suspending particles) is homogeneous and uniform. The dielectric constant of the medium (this will be referred to by the term storm) depends on the intensity of dust particles per unit volume of air, the polarization of the wave relative to the particles axes, etc. The dielectric constant of the medium with suspending ellipsoids is given by [15].

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$$\varepsilon_i = \varepsilon_a \left(1 + v \frac{\varepsilon - \varepsilon_a}{\varepsilon_a + A_i (\varepsilon - \varepsilon_a)}\right) \quad i = 1,2,3 \tag{6}$$

Where: ε_i is the dielectric of the medium with suspending ellipsoids, ε is the dielectric constant of the ellipsoids material, (dust or/and sand particles), ε_a is the dielectric constant of the medium in which ellipsoids are suspending(in our case air), v is the relative volume occupied by particles, A_i is the depolarization factor along the a_i axis as explained in Figure1, and is defined by using the following equation:

$$A_i = \frac{a_1 a_2 a_3}{2} \int_{-\infty}^{\infty} \frac{ds}{(s + a_i^2)[(s + a_1^2)(s + a_2^2)(s + a_3^2)]^{1/2}} \qquad i = 1,2,3 \tag{7}$$

For air with suspending dust and/or sand particles, Eq. (6) reduces to [5], [18].

$$\varepsilon_i = \left(1 + v \frac{\varepsilon - 1}{\varepsilon_a + A_i (\varepsilon - 1)}\right) \quad i = 1,2,3 \tag{8}$$

Consider the ellipsoid geometry shown in Figure 1, with the semi axes fall in the order $a_1 > a_2 > a_3$, (a_1,a_2 and a_3 are orthogonal directions). The depolarization factor in the I direction is given by Eq.(7), and by integration we get: [5], [15]

$$A_i = \frac{r_1 r_2 [f(x,m) - \pi(n,x,m)]}{\sqrt{1 - r_2^2}(1 - r_i^2)} \tag{9}$$

Where: f(x, m), π (n, x, m) are incomplete elliptic integral of the first kind and third kind respectively.

The depolarization factor in the 1, 2 and 3 directions are obtained as follows:

$$A_1 = \frac{r_1 r_3}{\sqrt{(1 - r_3^2)(1 - r_2^2)}} [f(x,m) - E(x,m)] \tag{10}$$

$$A_3 = \frac{r_2^2}{r_2^2 r_3^2} [r_2 \frac{r_3}{\sqrt{1 - r_3^2}} - E(x,m)] \tag{11}$$

Where: $f(x,m)$ the Elliptic integral of the first kind and $E(x,m)$ the second kind, the Solution of Elliptic Integral of First Kind and the second kind given by. [15]

V. Analysis

A. Dust Complex Permittivity

From the values of the complex permittivity and the relative volume of all substances, we can calculate the complex permittivity of the composite component by using the Looyenga equation as given by. [17]

$$\varepsilon_m^{1/3} = \sum_{i=1}^{n} \varepsilon_i^{1/3} v_i \tag{12}$$

Where ε_m is the complex dielectric constant of the mixture, ε_i is the complex dielectric constant of the ith substance.[5], v_i is the relative volume of the ith sample from the volume of the total sample.

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The analysis of these samples was done in laboratories of the Libyan Petroleum Institute and Lebda Plant in AL-Khoms. The average density of all samples are equal to 2.3275 gm/cm^3, and the Results of .The average of complex permittivity of samples equal to ε_m =6.0891-j0.1656.

B. Estimate of Air Relative Humidity

The complex permittivity depends on moisture contents in samples. Sharief [15-17] arrived at the following empirical relation for the variation of complex permittivity with relative humidity.

$$\acute{\varepsilon} = 6.0891 + 0.04H - 7.78 * 10^{-4}H^2 + 5.56 * 10^{-6}H^3 \quad (13)$$

$$\ddot{\varepsilon} = 0.1656 + 0.02H - 3.71 * 10^{-4}H^2 + 2.76 * 10^{-6}H^3 \quad (14)$$

C. Estimation of the Attenuation for Spherical Particles

In this section we will use exactly the same expression obtained by Samir I. Ghobrial [8] using an analysis based on the work of Maxwell Garnett. Also the effect of the height (height of towers) on the visibility there by its effect on both the attenuation and the cross-polarization constants in this region.

$$\alpha = \frac{2.46 * 10^5 * v}{\lambda} * \frac{\ddot{\varepsilon}}{[\,(\acute{\varepsilon} + 2) + \ddot{\varepsilon}^2\,]} \quad (15)$$

$$v = \frac{C}{\rho * V_0^{\gamma}\,(h/h_0)} \quad (16)$$

Where*:* λ is the wavelength (in meters), V_o is the visibility at h_o, its minimum value is about 8m, *ho*=2m is the reference height, **ε=6.0891-j0.1656** is the complex permittivity of dry samples, and ρ is the average measured density of the samples collected in the studied region which is **2.3275gm/cm^3**.

By using Computer program (Matlab), the results are shown in Figure 3.

D. Estimation of the Attenuation for Non- spherical Particles

The propagation constant of the Dust storm is given by: [15]

$$\gamma_i = \alpha_i + j\varphi_i \quad (17)$$

The attenuation and phase shift constants are obtained as the average of all α_i and , φ_i respectively, thus:

$$\alpha = -\frac{\pi}{3\lambda}\sum_i Im \frac{v}{A_i + {}^{1}/_{(\varepsilon - 1)}} \quad (18)$$

$$\varphi = \frac{\pi}{3\lambda}\sum_i Re \frac{v}{A_i + {}^{1}/_{(\varepsilon - 1)}} \quad (19)$$

Equations (18) and (19) may be used to determine the attenuation and phase shift when a wave of known polarization propagates through a storm.

A circular polarized wave may be resolved into two linearly polarized waves of equal magnitudes but with their

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polarizations orthogonal and 90° out of phase. Since the attenuation and phase constants for vertical and horizontal polarizations in a storm are not the same, cross polarization is induced. It is known that the cross-polar discrimination (XPD) for a circular polarized wave is given by. [15], [17]

$$XPD = 10\log_{10}\left| {1 + 2m\,cos\varphi + m^2}\Big/{1 - 2m\,cos\varphi + m^2} \right| \qquad (20)$$

The quantities m and φ can be determined for a wave propagating in a storm immediately as follows:

$$m = e^{|\alpha_h - \alpha_V|D} \qquad (21)$$

$$\varphi = (\varphi_h - \varphi_V)D \qquad (22)$$

Where: D is the path length in the storm in kilometers.

The attenuation of a circularly polarized wave given by: [5]

$$att(dB) = -20\log \sqrt{\frac{1 + 2m\,cos\varphi + m^2}{4}}\; e^{-\alpha_v D} \qquad (23)$$

Assumed all dust particles to be ellipsoids with axes ratios equal to the average axes ratios $a_1 : a_2 : a_3 = 1 : 0.71 : 0.53$. of some 500 particles that were studied using microscopic measurements.

These ratios are in good agreement with the results obtained by McEwan and Bashir. [22], [15]. We can use the equations obtained by S.I. Ghobrial and S. M Sharief [5]. To estimate the attenuation and phase constants for vertical and horizontal polarization.

To evaluate the attenuation and phase constants for vertical and horizontal polarization the quantity x defined by:

$$x_i = \sum_i \frac{1}{A_i + {1}/{(\varepsilon - 1)}} \qquad i = 1,2,3 \qquad (24)$$

Was evaluated for two values of ε these are the dielectric constant of dust with relative humidity 21% and 72%. Table:I gives the outcome of these computations. The values of A_1, A_2, and A_3 were taken from Eq. (12), and (13).

From equations obtained by S.I. Ghobrial and S. M Sharief [5], [15], the attenuation and phase constants for vertical polarization and horizontal polarization can be written as:

$$\alpha_V = -\frac{\pi}{\lambda}\, v\, Imx_3 \qquad (25a)$$

$$\varphi_V = \frac{\pi}{\lambda}\, v\, Rex_3 \qquad (25b)$$

$$\alpha_h = -\frac{\pi}{2\lambda}\, v\, Im(x_1 + x_2) \qquad (26a)$$

$$\varphi_h = -\frac{\pi}{2\lambda}\, v\, Re(x_1 + x_2) \qquad (26b)$$

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Using Equations.(2), (18), (19), and (20), and values of 'x_i' given in Table :I, the following expression for attenuation and phase constants were obtained in terms of visibility V, wavelength λ, and path length D in the storm:

For relative Humidity (H=21%): ε = 6.638-j0.448:

$$\alpha_v = 4.2464 * 10^{-4} D/(\lambda V^{\gamma}) \quad (27a)$$

$$\Phi_v = 0.1878 * D/(\lambda V^{\gamma}) \quad (27b)$$

$$\alpha_h = 5.0 * 10^{-3} D/(\lambda V^{\gamma}) \quad (28a)$$

$$\Phi_h = 0.6348 * D/(\lambda V^{\gamma}) \quad (28b)$$

For relative Humidity (H=72%): ε = 7.011-j0.713:

$$\alpha_v = 6.0552 * 10^{-4} D/(\lambda V^{\gamma}) \quad (29a)$$

$$\Phi_v = 0.1911 * D/(\lambda V^{\gamma}) \quad (29b)$$

$$\alpha_h = 7.7 * 10^{-3} D/(\lambda V^{\gamma}) \quad (30a)$$

$$\Phi_h = 0.6631 * D/(\lambda V^{\gamma}) \quad (30b)$$

In the above expressions λ is the wavelength in centimeter, V is the visibility in kilometers, D is the path length in the storm in kilometers; and ' γ ' is a constant equal to 1.07.

We will be using Equations. (21-30) to calculate the attenuation for a circularly polarized wave, and calculate the phase difference between horizontally and vertically polarized waves as a function of visibility for a path length of 1 km, and we can use the Eq. (20), to estimate the cross polarization discrimination for values of path length. The results are given in Figure.4, and 5.

Table I: Dielectric Constant of Dust with relative humidity 21% and 72%

dielectric constant (ε)	**X_1**	**X_2**	**X_3**
6.638-j0.448	4.3325-j0.2636	2.8032-j0.1101	1.0606-j0.0157
7.011-j0.713	4.5563-j0.4069	2.898-j0.1638	1.0743-j0.0225

Submitted 29 July 2022; Final Version Received 19 Oct. 2022; Accepted 09 Sep. 2022; Published Online in Dec. 2022

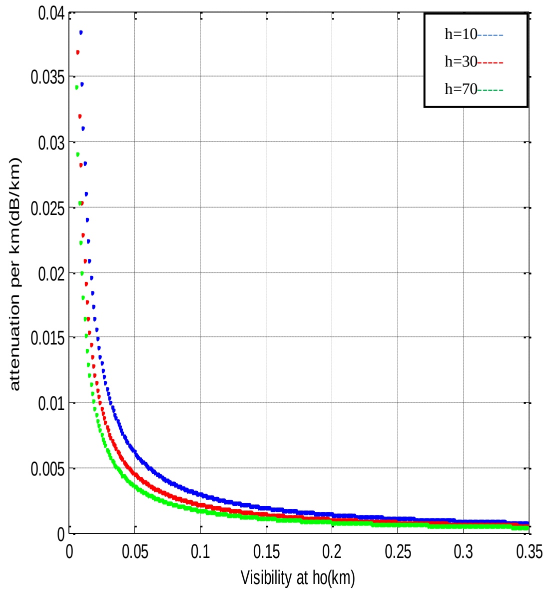

Figure.3. *Attenuation per km at H=21 % and for height=10, 30 and 70m*

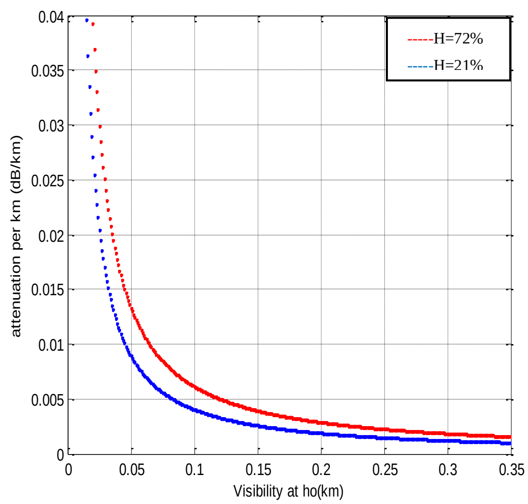

Figure.4 *Attenuation per km at height= 10m and for H=21%, 72%*

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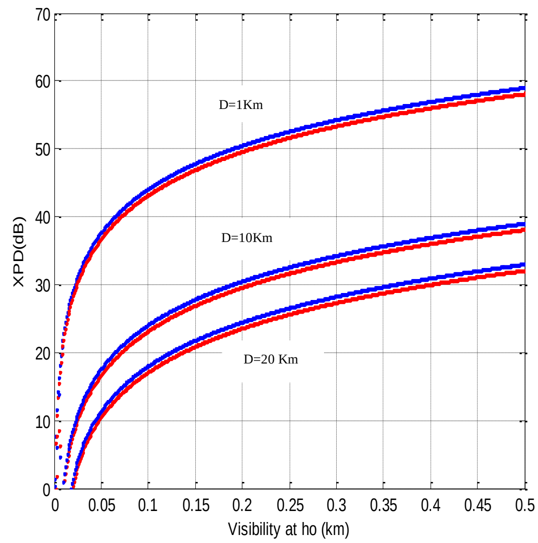

Figure.5.*Cross Polarization Discrimination (dB) at height= 10m.*

VI. CONCLUSION

This paper studied the impact of Sand Particle-Size Distribution on microwave propagation in the study area. The results of this paper can be summarized in the following points:

- The major constituents of samples are SiO_2, $CaCO_3$ and AL_2O_3 about 80% by weight of samples, and The average density of all samples equal to **2.327gm/cm3**
- The average of complex permittivity of dry soil equal to **6.0891-j0.1656** and equal to **7.011-j0.713** at maximum relative humidity for the studied area.
- The attenuation for spherical particles in with visibility equal 8m (worst case) at a humidity 21% at any height, equal **(0.0408dB/km** respectively).The attenuation for non-spherical particles with visibility equal 8m (worst case) at a humidity 21% and 72% at any height, equal **(0.0729dB/km** and **0.1004dB/km** respectively).
- For circular polarization, cross polarization can be serious when visibilities fall below 100m over about 10km of path. or below 10m over about 1km of path .
- For visibilities less than 50m phase difference between horizontal and vertical polarizations increases rapidly with decreasing visibility.
- The effect of dust humidity on phase difference and cross polarization is not significant for different visibilities.
- Simple expressions for attenuation and phase shifts of linearly polarized waves were derived in terms of the path length, wavelength, and visibility.

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